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High-Intensity Muon Storage Rings for Neutrino Production: Lattice Design

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High-intensity Muon Storage Rings for Neutrino Production: Lattice Design

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Abstract. Five energies, 250, 100, 50, 20, and 10 GeV, have been explored in the design of a muon storage ring for neutrino-beam production. The ring design incorporates exceptionally long straight sections with large beta functions in order to produce an intense, parallel neutrino beam *via* muon decay. To emphasize compactness and reduce the number of muon decays in the arcs, high-field superconducting dipoles are used in the arc design.

INTRODUCTION

The very intense muon sources being considered in current muon collider design studies are also an intense source of neutrinos due to muon decay. As first noted in [1], if the muons are stored in a ring with a long straight section, an intense neutrino beam is realizable. In this paper designs for such muon storage rings are discussed.

Since the source beam is retrieved and recirculated, muon storage rings are capable of generating very intense, uncontaminated neutrino beams in long field-free regions or straight sections. For acceleration and storage, muons are favored over pions because of their enhanced lifetime (factor of 100). The secondary neutrinos produced take on the characteristics of the parent muons, albeit with an increase in divergence given by the decay angle, p/m_μ. The emittance of the muon beam combined with the design optics therefore completely determine neutrino beam properties. The fact that bremsstrahlung may be ignored means that muons can be manipulated similar to protons of the same momentum, making lattice attributes and performance resemble proton machines. The rest of this paper is devoted to a discussion of simple lattices designed specifically to enhance neutrino production.

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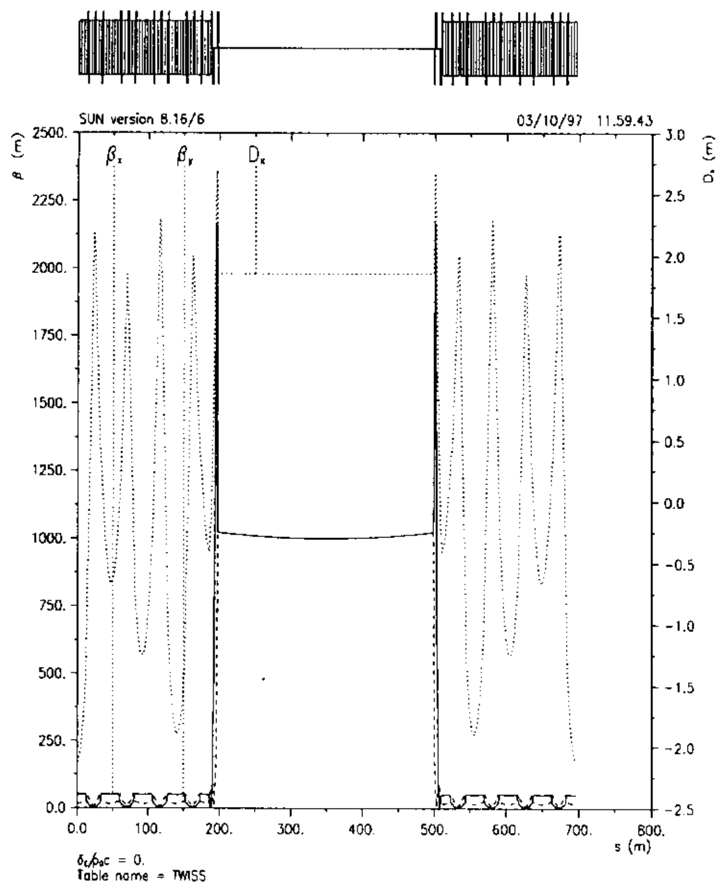

FIGURE 1. 250-GeV half-ring design.

RING DESIGN CRITERIA

Muon storage rings were designed for five possible energies: 250 100, 50, 20, and 10 GeV. As can be seen in Fig. 1 and Fig. 2, the basic ring design follows a simple racetrack layout. All rings contain superconducting dipoles with 8T poletip fields. For normal conducting dipoles, ring energies are reduced by a factor of 5 to 6; i.e. the energy of 10-GeV ring design becomes 1.5 GeV.

The use of superconducting dipoles is essential in a low-energy muon storage ring to minimize arc length and therefore the number of muon decays in the arcs. Respective arc lengths in the 250-GeV design and 10-GeV design are 400 m and 60 m. Initially the neutrino beam was directed vertically downward in both long straights at a 45° angle with arcs on opposite sides of the ring at different altitudes. Adding the needed 180° of vertical bend to align both

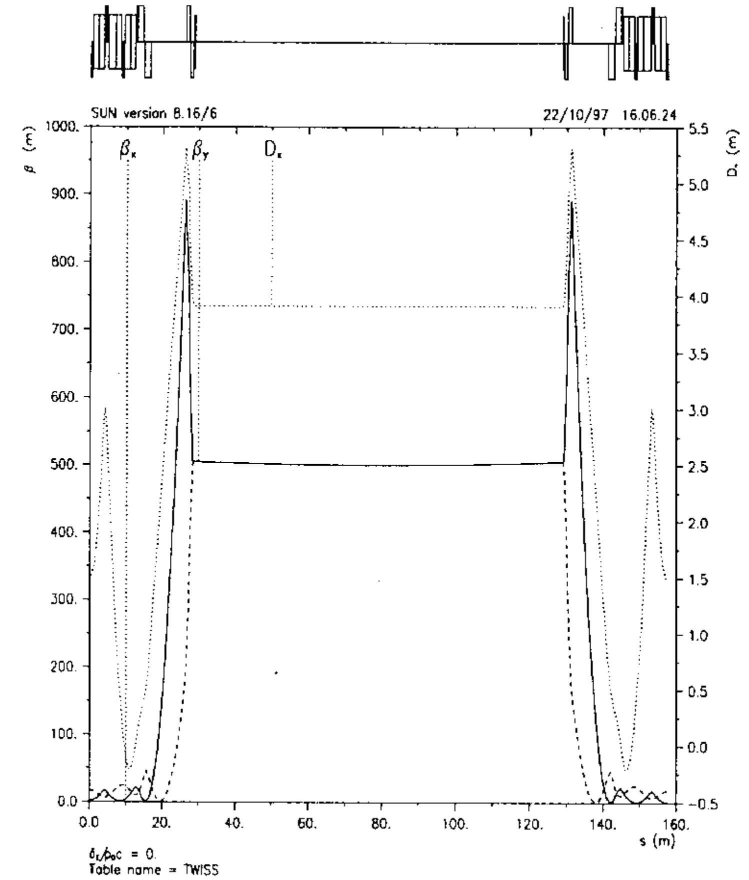

FIGURE 2. 10-GeV half-ring design.

arcs in a horizontal plane increased the circumference by more than 50% and compromised the compactness of the ring. A better approach is to tilt these tightly compacted rings vertically. Since the highest energy ring is 111 m in radius, a 51° pitch means the height changes by ± 86 m at 250 GeV. For 10 GeV it is ± 20 m. In either approach, one side of the ring produces a neutrino beam directed upwards so that a restricted radiation area will likely be needed where the upward neutrino beam emerges. The downward neutrino beam can be carefully aimed through the earth and onto a remote detector by measuring and controlling the trajectory of the parent muon beam [1].

The long production straights range in length from 300 m at 250 GeV decreasing to 100 m at 10 GeV and have a high beta consistent with the desired neutrino-beam properties; that is, the intrinisic divergence of the muon beam must be much less than the decay angle so that the decay kinematics dominate [1]. Initially, high-betas of 500 m to 1 km were chosen so that the muon beam emittance could be very large yet meet the divergence criteria in the long production straights. (Large muon emittances imply less cooling upstream of the storage ring.) With a beta of 1 km and a normalized rms emittance of $2000\pi\ mm - mr$, the divergence of a 250-GeV muon beam is only 0.03 mr, which is to be compared with the 0.4 mr decay angle. At 10 GeV, the decay angle is 10 mr. For the same normalized emittance, a high-beta of only 40 m gives a divergence which is much less then the decay angle in comparison–0.72 mr. (The decay angle scales as $1/\gamma$ while the divergence scales as the square root of $1/\gamma$.) The above parameters were kept consistent with 15-cm half-aperture quadrupoles which will be required to match the arcs into the production straights. In the following section the optical properties of the lattice will be described.

LATTICE OPTICS

As stated, the ring lattice is a simple racetrack with a doublet forming the high-betas in the long straights. Triplet quadrupole structures would remove the spike in the beta functions and will likely replace the simple doublets in future lattices. The highest energy lattices, the 250 and 100 GeV employ flexible momentum compaction (FMC) modules in the arcs and this parameter can be controlled. The lattice design reverts to a simple FODO structure at the other energies when the dipole becomes too strong for a short FMC module. Although the dipoles have 8T poletip fields nominally in all designs for compactness, the quadrupoles in the lower energy rings are normal conducting when they became too short.

The low beta values in the arcs (20-30 m) imply no significant natural chromaticity. The high-beta inserts, however, will require some local chromatic correction using sextupoles.

CONCLUSIONS

A muon storage ring (without a low-beta interaction region) is straightforward and similar in design to proton machines with the same momentum. The quoted normalized emittance acceptance appears drastically high for muons because of their small mass when compared with protons. Beam sizes are, however, comparable to proton beams. The lattices presented in this paper are designed for maximum compaction in the arcs and large transverse acceptance (the equivalent normalized rms acceptance for a proton beam would be $200\pi\ mm - mr$). The acceptance is ultimately constrained by the large apertures required for the high-beta insert quadrupoles. Unless significant field errors are present, the arcs will not require chromatic correction. Local chromatic correction of the high-beta insert will be required for good momentum acceptance ($\sim \pm 0.5\%$).

REFERENCES

1. S. Geer, Neutrino Beams from Muon Storage Rings: Characteristics and Physics Potential, Fermilab-PUB-97/389 (hep-ph/9712290), submitted to Phys. Rev. D.